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Ex Ante Impact Assessment of Policies Affecting Land Use, Part A: Analytical Framework

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ABSTRACT. Contemporary policy making calls for scientific support to anticipate the possible consequences of optional policy decisions on sustainable development. This paper presents an analytical framework for ex ante assessment of economic, social, and environmental impacts of policy driven land use changes that can be used as an aid to policy making. The tasks were to (1) link policy scenarios with land use change simulations, (2) link land use change simulations with environmental, social, and economic impacts through indicators, and (3) value the impacts in the context of sustainable development. The outcome was a basis for dialogue at the science-policy interface in the process of developing new policies on the European level that impact on land and land use. The analytical approach provides a logical thread for ex ante impact assessment within the context of sustainable development, land use multifunctionality, and land use change and it provides a thorough discussion of achievements and open challenges related to the framework. It concludes with considerations on the potential for using evidence based ex ante assessments in the process of policy development. The paper is complemented by a B-paper providing exemplary results from two applications of the framework: a financial reform scenario of the Common Agricultural Policy of the European Union, and a bioenergy policy scenario for the case of Poland (Helming et al. 2011).

Key Words: *analytical framework; discussion tools; DPSIR-framework; ex ante impact assessment; land use change; model-based tools; participatory assessment tools; policy development; sustainability*

INTRODUCTION

Ex ante impact assessment for European policy making is carried out in several steps to analyze possible future implications of a policy before implementation (CEC 2009). After having identified the policy problem, the objectives are defined and the main policy options developed. For every option, the intended and unintended impacts on social, economic, and environmental variables of the system are to be analyzed and compared. Until the present, most impact assessments have focused on better regulation and higher policy efficiency, whereas less effort has been put into a balanced impact analysis equally considering all three sustainability dimensions (Hertin et al. 2007, Jacob et al. 2008). This may be accounted for by

preferences of decision making bodies. However, the integrated analysis of sustainability impacts is also hindered by a lack of evidence-based methods that provide the causal knowledge and linkage between policy intervention and sustainability impacts (Böhringer and Löschel 2006). Policy makers articulate their need for discussion support as an aid to policy making, preferably in the form of tools or methods that are flexible on the one hand and robust on the other (Thiel and König 2008). On account of this, comprehensive inventories of impact assessment tools have been conducted for a variety of policy fields (Böhringer and Löschel 2006, Van Herwijnen 2008). One shortcoming that was made obvious by the inventories was that most existing tools cover isolated aspects of impact assessment such as scenario analysis or accounting

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approaches but do not provide a comprehensive framework of analyzing causal chain relationships between policy induced system changes and corresponding system responses (Lotze-Campen 2008).

The need for a balanced assessment of all three sustainability dimensions is particularly relevant for policies related to land use. Land use comprises a combination of sectors and includes human activities that exhibit a spatial dimension and change the biogeophysical conditions of land. Impact assessment, therefore, has to consider simultaneously all spatially relevant aspects of these economic sectors as well as other activities that are linked to land. These include agriculture and forestry as main sectors, transport and energy infrastructure, rural tourism, and nature conservation as a 'regulatory activity' occupying land. Any policy change in one of these areas has the potential to also induce considerable land use changes in the other sectors. In particular, transnational land use policies can substantially influence market regimes in all affected sectors (Plummer 2009).

Because many European policies are related to land use through financial measures, the analytical link between policy options and land use changes has predominantly been economically based (Troy and Wilson 2007). However, land use is placed in a specific biogeophysical and socio-cultural setting that has to be considered when analyzing policy impacts in a sustainability context employing a spatially explicit approach.

Concerns about environmental impacts of changes in land use are not new. Extensive literature exists on land use patterns and intensities and the related environmental impacts, e.g., soil degradation (Pimentel 1993, Boardman and Poesen 2006), desertification (Reynolds and Stafford Smith 2002, Geist 2005), water quality, and biotic diversity (Poschloed et al. 2005). Interrelations between land use changes and ecosystem robustness and resilience have also been analyzed and modeled (e.g., Metzger et al. 2006). The role of land use in mitigation of and adaptation to climate change processes is one of the key discussion points in international debate (IPCC 2001, Graveland et al. 2002). When compared with economic processes and environmental impacts, social aspects of land use changes are less well understood (e.g., Ojima et al. 1994, Slee 2007; Rametsteiner et al. 2011). Also, the integrated and simultaneous analysis of the three

sustainability dimensions requires new approaches and a specialization in integrative sciences (Bammer 2005).

A number of modeling and foresight studies of land use change have recently been undertaken that indeed place land use into the logical chain of driving forces and impacts, the latter usually expressed in indicator changes (Veldkamp and Verburg 2004, Verburg et al. 2006, Nelson et al. 2009). For example, an advanced ecosystem analysis and modeling project (ATEAM) undertook scenario-based simulations on global climate and land use change impacts on ecosystem vulnerability in Europe (Rounsevell et al. 2006). Building upon this study, Klijn et al. (2005) addressed socioeconomic impacts associated with land use changes in the agricultural sector. The method allowed an anticipation of possible impacts of economic trends and policy choices on agricultural developments and related sustainability issues. Van Ittersum et al. (2008), also focusing on the agricultural sector, developed an approach for multiscale modeling to assess sustainability impacts of agricultural policies. Another study conducted for the European Environmental Agenda (Hoogeveen and Ribeiro 2007) developed scenarios for future land use changes in Europe. Designed as a facilitation instrument for public debate on landscape visions, various stakeholders developed a set of antithetical scenario narratives to envision landscape appearance in 30 years time. Extreme and partly shock-based socioeconomic developments and land use decisions were important features of these scenarios.

All of these interdisciplinary studies relate to ex ante analyses of future land use change scenarios based on a number of social, economic, and environmental indicators. This is a considerable advancement to earlier and more disciplinary studies. The role of indicators in these studies is twofold: first, they are means to compile and structure knowledge, i.e., science aspects; second, they express societal and political norms and priorities, i.e., normative aspect (Rametsteiner et al. 2011). This is to ensure both scientific soundness and policy relevancy. Government lead processes often focus mostly on norm creation, whereas the research oriented processes are dominated by science (e.g., Gamborg 2006, Frederiksen and Kristensen 2008, Alkan-Olsson et al. 2009). Various participatory approaches have been employed to complement the scientific approach with normative, stakeholder-

based perspectives and to set the scientific information in its social context (Gamborg 2006, Tabbush and Frederiksen 2008, Alkan-Olsson et al. 2009).

With the consideration of indicators of all three sustainability dimensions, these studies go a step further into sustainability assessment compared with earlier, more disciplinary studies. However, indicators are analyzed in parallel with no interaction. The missing links toward a comprehensive impact assessment lie in the integration of the indicator analyses according to the concept of sustainability and a valuation of these impacts in the light of sustainable development criteria (Helming et al. 2008). This would allow a discussion based on different perceptions and priorities toward land use change and sustainable development.

One key concept to operationalize sustainable development for land use and landscape development is the concept of multifunctionality (Wiggering et al. 2006, Cairol et al. 2008). What was initially a purely economic concept linked to the agricultural sector (Van Huylenbroeck et al. 2007), was developed to recognize the noncommodities, i.e., environmental and social services, produced in addition to the commodities, i.e., food and fiber, in a primary, market-oriented sector (Maier and Shobayashi 2001). Approaches were developed to make the concept operational for rural development and policy design (Durand and Van Huylenbroeck 2003, Bills and Gross 2005, Kallas et al. 2007) by linking the supply-based concept of joint production to an estimation of social demand for such functions. From there, links can be made to impact assessment (Barkman et al. 2004, Piorr et al. 2006, Zander et al. 2007). However, attempts at an integrated view of sustainability impacts are still rare (Wiek and Binder 2005). Territorial characteristics and landscape specificities as well as interrelations between different land use sectors also need to be addressed (Wiggering et al. 2003).

A strongly territorial concept toward sustainability analysis that came up in the area of landscape and ecosystem ecology was the concept of landscape and/or ecosystem functions (e.g., Forman and Godron 1986, Naveh and Lieberman 1994). The idea was that natural and seminatural ecosystems provide goods and services to human society that are of ecological, socio-cultural, or economic value

(Costanza et al. 1997, de Groot et al. 2002). Although the concept of ecosystem services was at first purely ecology-oriented and designed for the valuation of natural and seminatural ecosystems (de Groot et al. 2002), the Millennium Ecosystem Assessment (MA 2003) widened the concept toward socioeconomic aspects by integrating cultivated and urban areas. In the MA, the approach was conceptualized toward the valuation of the world's ecosystems with respect to their provisioning, regulation, supporting, and cultural functions affecting human well-being. It is widely acknowledged as an extensive concept for linking environmental processes to human well-being and services to society (Beck et al. 2006, TEEB 2009). However, its bias toward the environmental dimension may hinder its application for the case of valuating land use changes in the context of sustainable development because it addresses social and economic issues only indirectly as a consequence of environmental changes (Jones et al. 2006, Schöber et al. 2010).

This paper employs a combination of the economy-based concept of multifunctionality and the ecology-based concept of ecosystem services to design land use impact assessment in the context of sustainable development. The overall objective was to develop an analytical framework for ex ante assessment of economic, social, and environmental impacts of policy driven land use changes that can be used as an aid to policy making. The tasks were (1) to link policy options with land use changes, (2) to link land use changes with environmental, social, and economic impacts through indicators, and (3) to integrate a valuation approach of these impacts on sustainable development. This paper describes the analytical framework for the implementation of these three steps and provides a thorough discussion of achievements and open challenges related to the framework.

ANALYTICAL APPROACH TO EX ANTE IMPACT ASSESSMENT OF LAND USE POLICIES

The research focused on the ex ante assessment of intended and unintended policy effects on the three sustainability dimensions for the case of land use. The procedure was designed to support policy making on land use at the European level, such that it could be used in the impact assessment process. A number of methodological challenges were

associated with the analytical design. The analyses had to be prospective, build across disciplines, sectors, and sustainability dimensions, be spatially explicit, and include the valuation of simulated environmental, social, and economic effects in terms of sustainability impacts. Land use changes include changes of land cover, land use intensity and patterns, land use purposes, e.g., corn for fodder production or for bioenergy production, and land property rights. In essence, three consecutive questions had to be answered (Fig. 1):

1. What kind of land use changes are to be expected as a consequence of policy intervention?
2. Where will the expected changes take place and what environmental, social and economic effects would they induce?
3. Will the expected effects matter in terms of regional sustainable development?

The method used was to adapt and extend the DPSIR causal framework to the specific needs of ex ante impact assessment. The DPSIR framework was developed by the European Environment Agency (EEA) by extending an earlier version initially developed by the Organisation for Economic Co-operation and Development (OECD; Gabrielson and Bosch 2003). It was developed for the assessment of the relations between human activities and the environment and is comprised of the following elements: driving forces, pressures, states, impacts, and responses (Gabrielson and Bosch 2003). The approach has since been used in many studies where interaction between human behavior and environment was at stake (Niemeijer and de Groot 2006). It is particularly useful when scientific process knowledge has to be translated into knowledge for policy support, such as in the Thematic Strategy for Soil Protection of the European Commission (Van-Camp et al. 2004). As a tool for improved communication at the interfaces of research and policy as well as to the stakeholders, the DPSIR framework has been found to have an implicit bias toward the environment (Svarstad et al. 2008). The specific strength of the concept lies in its adaptability to many different objectives and scales of analysis. The focus in this case was laid on rural landscapes.

In the context of policy analysis, there are two sets of external *Drivers*: those drivers that span a future

socioeconomic and technological reference situation, and policy drivers. The consequential land use change is defined as the *Pressure* that is affected by both mentioned drivers. The role of *States* is taken by social, economic, and environmental characteristics that are affected by land use changes. They are quantified by indicators. Sustainability *Impacts* are meant to be derived by aggregating these indicators and translating them into services to society, which are provided through land use. They can then be valued by experts and stakeholders against sustainability perceptions. In this way, the analysis chain departs from a predominantly socioeconomic and economic setting (*Drivers*) that is translated into a geophysical setting (land use *Pressures*) and through the effects on environmental, social, and economic conditions (*State*) further into an integrated system of the social, economic, and environmental assessment (sustainability *Impacts*). Whereas the first two steps follow a mainly positivist approach, the third step is mainly normative in nature.

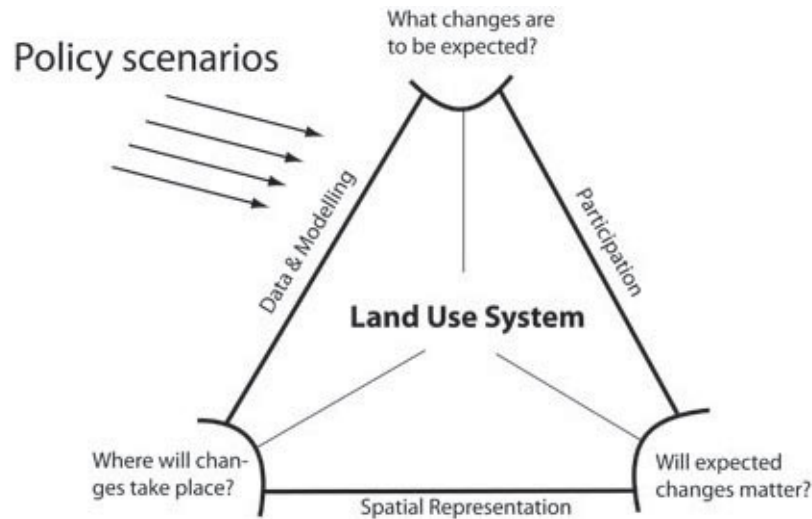
In its logical setting of the Impact Assessment procedure for European policy making (CEC 2009), the *Response* component would be covered by policy decisions in reaction to simulated impacts, thus completing the DPSIR cycle. Because these decisions were exogenous to this research, the component of Responses was not taken up in this analytical design.

Step 1: Translating drivers into pressures: What land use changes are to be expected?

Scenarios were developed to bundle the relevant driving forces into a future reference situation, against which the impact of a specific policy can be assessed. In other words, a reference scenario was necessary to present land use conditions that would be expected to develop in the absence of any policy intervention. A projection year of 2025 was selected to meet the policy makers' requirements for medium term perspectives.

Five driving forces were identified that together determine the economic situation in Europe within the projected time line. The driving forces selected were (1) demographic changes in Europe, (2) participation rate in the labor force in Europe, (3) growth of world demand, without considering Europe, (4) oil prices at the world market, and (5) expenditure on research and development, i.e.,

Fig. 1. Three consecutive questions to be addressed for impact assessment of land use policies.



technological advance. Climate change related parameters were not considered because current predictions state that it will not have significant impact on land use within the time span of the next 15 years (until 2025) considered in this research (IPCC 2001, 2007, Wiggering et al. 2008). Based on these driving forces, a storyline could be constructed for the year 2025 that would stand as a reference for a continuum of possible economic futures without a change in policies.

This setting was chosen as a reference scenario that allows policy scenarios to be analyzed against it. A selection of policy choice instruments for environmental, agriculture, forestry, transport, and bioenergy policy fields was then built to be able to determine the policy interventions that act as a second set of driving forces upon the business as usual scenario (fig. 2).

Scenario simulations were realized on the basis of quantitative modeling by coupling a macro econometric model (NEMESIS; Fougeyrollas et al. 2001) with sector models for agriculture (CAPRI; Heckeley and Britz 2001) and forestry (EFISCEN; Karjalainen et al. 2003). Models for the sectors tourism, urbanization, and transport and energy infrastructure were built directly into the macroeconomic model (Jansson et al. 2008).

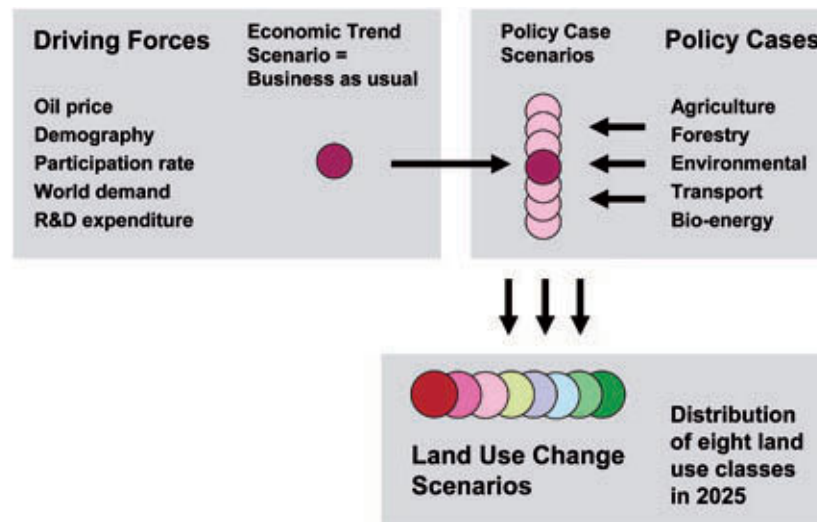
Resulting economic forecasts were then translated into land use simulations by linking sector models with a land use model (CLUE-S; Verburg et al. 2002).

The coupling of models resulted in a model chain that calculates the reference scenario as a business as usual scenario based on all five selected driving forces. The economic trend scenarios as well as the policy scenarios derived from the policy cases were translated into land use changes in a spatially explicit way at 1 km² grid level for eight land use classes by the model. The selected eight land use classes were (1) rainfed arable land, (2) irrigated arable land, (3) land devoted to biofuels, (4) grassland, (5) abandoned agricultural land, (6) built-up land, (7) forest, and (8) seminatural land. Special classes with little temporal dynamics such as beaches, glaciers, bare rock, and surface waters were summarized into an extra category (Verburg et al. 2008).

**Step 2: Translating pressures into states:
Where will land use changes take place and
what will they effect?**

For the analysis of the effects of policy induced land use changes on social, environmental, and economic

Fig. 2. Scenario design in the analytical approach: a suite of five socioeconomic driving forces constitute an economic trends scenario (upper left), which describes the reference for the choice of policy scenarios to act upon (upper right). Together they determine the land use change scenarios (lower right).



conditions, an indicator-based approach was employed. To be policy sensitive and to comply with the requirements of the impact assessment procedure for European policy making (CEC 2009) the selection of indicators was closely linked to the list of impact issues that is contained in the official guidelines for impact assessment of the European Commission (CEC 2009). All impact issues of that list were analyzed with respect to their relevancy in the land use context. If relevant, indicators were selected that best describe the respective impact issue. Indicators were preferably selected from existing indicator systems (Frederiksen and Kristensen 2008).

Further indicator selection criteria were: (1) sensitivity to the above mentioned land use types, (2) sensitivity to the reference and policy scenarios, (3) sensitivity in relation to the chosen time frame and spatial system based on the 'Nomenclature of Territorial Units for Statistics' of EUROSTAT that subdivides the European member states into units following administrative boundaries (regional, NUTS 2/3 scale), and (4) data availability and operability. Indicators were chosen in such a way that the selection is balanced across the three sustainability pillars. In total, 50 indicators were

selected so that each of the relevant impact issues of the European Commission Impact Assessment Guidelines could be described with at least one indicator (Table 1).

Generally, indicators were quantified at NUTS 2/3 scale or with higher (1 km²) resolution and reaggregated to NUTS 2/3. Deviation occurred for some of the social and economic indicators for which data restrictions only allowed for indicator determination at the national level. In those cases, results were only displayed at the national level. All indicators were determined for the entire area of the 27 European Union member states. For indicator determination (calculation) the outputs from the above mentioned scenario calculations were used. In some cases additional static data were needed. To allow for reproducibility and automation, solely publicly available data and model outputs were used for indicator determination. Qualitative methods for indicator determination were employed in cases where knowledge and/or data restrictions made quantifications impossible (Farrington et al. 2008). Methods for indicator determination were based on state of the art knowledge rules and models (Bach et al. 2008). Of the 50 indicators suggested, in total 23 indicators could be determined based on the

Table 1. Selected impact issues from the EC Impact Assessment Guidelines (CEC 2009) and respective indicators selected for this study.

Selected impact issue from the EC Impact Assessment Guidelines(CEC 2009)		Selected Indicators
ENV 01	Air quality	Ammonia emission from agriculture; Nitrogen oxide (NOx) emissions
ENV 02	Water quality and resources	Nitrogen (N) surplus; phosphorus (P) surplus; water abstraction; water retention capacity of the soil
ENV 03	Soil quality and resources	Soil erosion risk by water; soil sealing; wind erosion; soil carbon content
ENV 04	The climate	CO2 emission; methane and nitrous oxide emission; carbon sequestration in biomass, soil and dead organic matter
ENV 05	Renewable or nonrenewable resources	Renewable energy production – biomass
ENV 06	Biodiversity, flora, fauna, and landscapes	Terrestrial habitats at risk from eutrophication; farmland and woodland birds; deadwood; high nature value farmland; spatial cohesion; pesticide use
ENV 07	Land use	Land use change (in 9 classes)
ENV 08	Waste production/generation/recycling	Generation of municipal waste by tourists; discharge of sewage water because of tourism
ENV 09	The likelihood or scale of environmental risk	Forest fire risk; flood risk
ENV 10	Mobility (transport modes) and the use of energy	Energy used by transport; Energy used heating and electricity
ECO 01	Competitiveness, trade, and investment flows	Net flows of traded goods in agriculture, forestry, and the energy sector
ECO 03	Operating costs and conduct of business	Labor cost; energy cost
ECO 04	Administrative costs on business	Administrative costs
ECO 05	Property rights	Property rights
ECO 06	Innovation and research	Labor productivity
ECO 07	Consumers and households	Inflation rate - consumer price index
ECO 08	Specific regions or sectors	Gross value added per sector (agriculture, forestry, tourism, energy)
ECO 10	Public authorities	Public expenditure
ECO 11	The macroeconomic environment	Gross domestic product
SOC 01	Employment and labor markets	Unemployment rate, employment by sector (both sectoral and total)
SOC 03	Social inclusion and protection of particular groups	Deviation of regional unemployment, deviation of regional income
SOC 04	Equality of treatment and opportunities, nondiscrimination	Gender impact of income distribution
SOC 07	Public health and safety	Exposure to air and water pollution; exposure to natural hazards
SOC 08	Crime, terrorism, and security	Self-sufficiency index for food; Self-sufficiency index for energy
SOC 09	Access to and effects on social protection, health, and educational system	Migration pressures
SOC 10	Tourism pressure	Social tourism pressure; recreational pressure from tourism
SOC 11	Landscape identity	Continuity of appreciated landscape heritage; change of visual attractiveness

modeling outputs and other available data. For the remaining 27 indicators, methodology constraints or data/modeling output constraints restricted the applicability (Bach 2008).

Step 3: Translating state changes into sustainability impacts: Will expected changes matter?

In this step, indicator results were integrated to derive a valuation in the context of sustainable development. The prevalent quantitative procedure to value policy impacts would be a monetary one. This would allow for the determination of the monetary magnitude for external costs and benefits associated to observed indicator changes. Monetary valuation has the evident advantage that it transforms the complexity of policy induced land use change impacts into only one unit policy makers are used to (Ortiz et al. 2009). The disadvantage is twofold. First, the methodology for monetary valuation is still poorly developed and available data and reference values are either very generic or developed for specific cases and difficult to transfer (Costanza and Farber 2002). Second, the normative complexity of stakeholder perceptions toward impact valuation is difficult to capture. The latter is particularly important to adequately embrace the value-based character of the sustainability definition (WCED 1987). Consequently, a nonmonetary, stakeholder inclusive approach was favored in this study. It is based on the concept of Land Use Functions, which is used to aggregate the complexity of indicator results into an operational basis that is comprehensible to stakeholders. They value the anticipated changes according to the importance of the Land Use Functions in their specific regional context. This procedure is described in the following sections.

Land Use Functions (LUF) were defined as those goods and services that are produced through land use in its interaction with the geophysical and socio-cultural capital of the landscape and that summarize the most relevant societal, economic, and environmental issues of a region (Pérez-Soba et al. 2008). Three LUF were defined for each of the three sustainability dimensions (Table 2). To overcome the strict separation between the sustainability dimensions, each of the LUF has its value also for the two other sustainability dimensions. The LUF approach combines the concepts of multifunctionality and of ecosystem services thereby allowing for an

equal consideration of the three sustainability dimensions in a fully spatial context. Three perspectives were considered: (1) the land use perspective, (2) the landscape perspective, and (3) the societal perspective (Fig. 3). The land use perspective represents the production side of land use functions. This is the dynamic perspective in which land use changes are introduced through policies and management decisions. The landscape perspective provides the spatial context and represents the geophysical and socio-cultural capital. It determines how far a certain region may perform in providing Land Use Functions with a given land use. For example, sandy, dry areas perform less well with respect to land based production (LUF 5) under a given land use than areas with better soils and more rainfall. The land use and the landscape perspective together make up the supply side of Land Use Functions. The societal perspectives finally represent the demand side for Land Use Functions. It actually determines the comparative importance and value of the nine Land Use Functions in a specific regional and time frame. This way, supply of and demand for Land Use Function can be confronted to allow for an estimation of sustainability for a given land use in a given area and time perspective.

To determine the Land Use Function, linear additive models were used to weigh and aggregate selected indicators to Land Use Functions allowing the evaluation of impacts at an international scale, e.g., the European Union, or on selected regions (Paracchini et al. 2011). The latter is based on a Spatial Reference System that clustered Europe into 30 regions employing socioeconomic and geophysical parameters (Renetzeder et al. 2008). The indicator aggregation procedure included (1) quantifying the contribution of each indicator to each LUF, and (2) developing knowledge rules to assess the importance of each LUF for the sustainability of each region. The latter allowed the introduction of a regional specificity into the interpretation of indicators (Paracchini et al. 2011).

In displaying the land use policy induced changes on Land Use Functions, alternative policy options can be valued and compared in their implication to these functions simultaneously. The LUF valuation is therefore a normative, participatory approach of valuation that consolidates the assessment results into a sustainability interpretation. The attribution of perception is done by the group valuation method, allowing the quantification of

Table 2. Land use functions used for indicator aggregation and impact valuation (Pérez-Soba et al. 2008).

Mainly societal land use functions

1. Provision of work: employment provision for all activities based on natural resources, quality of jobs, job security, and location of jobs (constraints, e.g., daily commuting).
2. Human health & recreation (spiritual & physical): access to health and recreational services, factors that influence service quality.
3. Cultural: landscape aesthetics and quality, and values associated with local culture.

Mainly economic land use functions

4. Residential and land independent production: provision of space where residential, social, and productive human activity takes place in a concentrated mode. The utilisation of the space is largely irreversible because of the nature of the activities.
5. Land-based production: provision of land for production activities that do not result in irreversible change, e.g., agriculture, forestry, renewable energy, and land-based industries such as mining.
6. Transport infrastructure: provision of space used for roads, railways, and public transport services, involving development that is largely irreversible.

Mainly environmental land use functions

7. Provision of abiotic resources: the role of land in regulating the supply and quality of air, water, and minerals.
 8. Provision of habitat: factors affecting the capacity of the land to support biodiversity, in the form of the genetic diversity of organisms and the diversity of habitats.
 9. Maintenance of ecosystem processes: the role of land in ecological supporting functions such as soil formation and energy buffering.
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preferences (Pérez-Soba et al. 2008). This provides the first point of discussion in stakeholder workshops. As a result, the assessment of land use change impacts funneled into an estimate of changes of the performance of these nine Land Use Functions. The impacts were then assessed by comparing the performance of the Land Use Functions with and without policy intervention. In this way, a trade-off analysis can be derived (Morris et al. 2008). The procedure can be applied with different stakeholder groups, depending on the specific objective, ranging from, e.g., policy makers at European level, i.e., decision makers, and stakeholders in a specific affected region, i.e., decision takers.

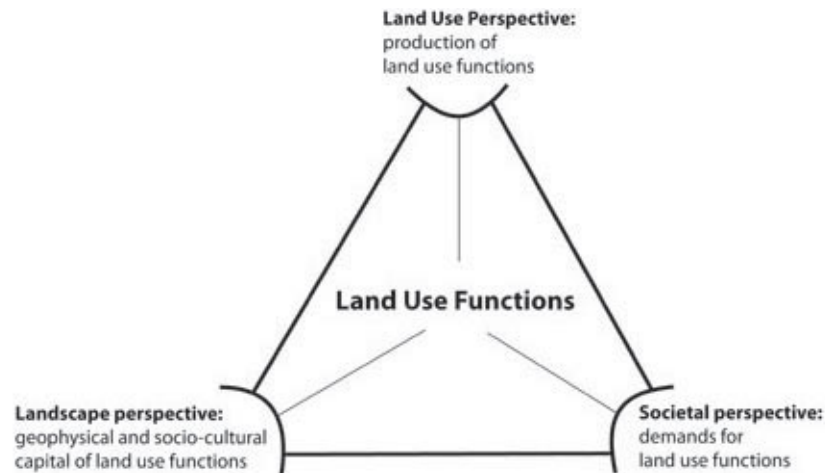
The output, i.e., stakeholder-based valuations of the modeling chain, indicator results, and respective

Land Use Function changes, can be communicated to the decision maker. Policy decisions in reaction to the simulated impacts and stakeholder valuations would complete the DPSIR cycle with the Response component. While exemplary results of the impact assessment framework application are summarized in a second paper (Helming et al. 2011), this paper continues with a reflexive discussion of the framework developed.

DISCUSSION

Impact assessment in the European Union is a broad process, through which policies are developed (Tscherning et al. 2008). In 2002, the Commission introduced impact assessment as a formalized procedure to structure the way policies are

Fig. 3. Triangle of perspectives affecting the performance of Land Use Functions: capital, supply, demand.



developed and their implications are assessed (CEC 2009). Practices of impact assessment have evolved and changed since the beginning of our research reported here, however, the basic procedure can be described in six steps: (1) identification of the problem, (2) definition of objectives, (3) development of policy options, (4) analysis of impacts, (5) comparison of options, (6) outlining of policy monitoring and evaluation (CEC 2009). To guarantee a certain standard, impact assessment guidelines make specific suggestions on how to deal with each step in this process. Several administrative units are in charge of assisting the policy development procedures. Besides adaptability and flexibility to emerging information needs, the complex and interdisciplinary nature of causal chain relationships behind the assessment questions was one of the biggest challenges in supporting impact assessment with evidence-based research.

We found that the adaptation of the DPSIR causal framework to the specific needs of ex ante impact assessment of economic, social, and environmental aspects of land use change was very useful particularly regarding interdisciplinary communication on the research side. It has proven successful for setting up a structure for an integration of disciplinary research that is policy oriented from the start. It captures the full causal chain from land use driving forces to its impacts and it is directly linked

to a policy question. The outputs can feed into steps (4) analysis of impacts, and (5) comparison of options in the process of carrying out the impact assessment.

Although each discipline offers just a partial view on the impacts without considering the relation of the systems, it is a precondition in natural resource management to have an eye for the environmental, economic, and social impacts of regulatory initiatives (Buanes and Jentoft 2009). By using the Land Use Functions as an aggregated application of an indicator framework, we see a successful integration of indicators balanced across the three pillars of sustainability on the level of land use. Land Use Functions are a pragmatic way to identify and classify sustainability issues related to land use change on the regional scale, and to communicate to decision makers trade-offs between environmental, economic, and social issues resulting from land use changes (Schöber et al. 2010). Effects and trade-offs not initially anticipated by policy makers can be revealed and taken into account. The process is under more control if possible indirect effects are taken into consideration early on, but this requires a broader view in the decision making situation (Buanes and Jentoft 2009).

The understanding of socioeconomic and cultural drivers should be broadened, and it is pivotal to the

proper analysis of social, economic, and cultural conflicts that surround the issue in focus. Thus, there is a particular need for elaboration of methodology to address attitudes and definitions of the problem held by stakeholders and the general public (Svarstad et al. 2008).

Given the current procedure of policy making at European Union level, stakeholders have an institutionalized direct influence neither on policy drafting nor on impact assessments. However, they are consulted and they lobby the various sectoral Directorates-General as well as the European Parliament and Council. Diffuse interests search for access to the European Parliament, also preferably targeted by environmental NGOs, rather than the Commission whereas the reverse is true for specific interests. Stakeholders often have deep knowledge of the issues at stake. Their professional success and remuneration is linked to an understanding of how sectoral interests find their way into policies. Their information processing capacities depend on the resources that the sector provides for interest representation. The representation of environmental interests is often much less resourceful than the representation of economic interests (Thiel 2009).

Although stakeholders have an impact on policy making through the lobby and consultation processes, this impact is informal and lacks institutional methods integrated into the process. When applied to steps (4) analysis of impacts and (5) comparison of options, the analytical framework reported here was found to be a useful basis for stakeholder consultations. In comparison with other approaches to impact assessment, this framework includes an additional step in assessing the normative value of land use changes. The normative valuation was accomplished by stakeholder participation. This translation into an anthropocentric view supports a political discussion and opens opportunities for an institutionalized stakeholder inclusion into the impact assessment process.

What is not covered with this framework is the dialogue at the science-policy interface. From the start, the response component was omitted because the decision making falls under the responsibility of the policy maker, the user of the analytical framework. However, even before coming to the response component of the process, a dialogue could take place between researchers and policy makers about the policy objectives and the outcome of the integration of results and the valuation process with

the stakeholders (Weaver and Jordan 2008.). This dialogue affords further research for better communication models (Pregernig 2006).

The challenge remains to integrate complex systems knowledge into clear, easy to comprehend information on the one hand, while maintaining necessary detail about sensitive systems relations on the other. To be useful in the decision making processes, assessment approaches should be designed in close cooperation with the potential user, and applied and tested in actual policy and decision making processes (Schöber et al. 2010).

One difficulty in the science-policy dialogue is the quantification of impacts. Monetization is discussed in context of the concept of Ecosystem Services, and the discussion was raised also during the application of the analytical framework described here. The concept of ecosystem services focuses mainly on economic impact of their marginal indicator change, whereas Land Use Functions provide a rather comprehensive perception of policy impacts, which rather fits to the holistic concept of sustainable development. The question was, whether a monetary valuation would make the approach more appealing for policy making and it seems true that policy makers are moved mainly by economics. Although the method of monetarizing marginal values leads to a systematic underestimation of the capital of natural resources, a monetarization of the Land Use Functions could lead to an appreciation of the value of the goods and services provided, because natural resources can only fulfill their functions as long as various critical stocks are permanently maintained. The monetary valuation at the level of Land Use Functions rather than at the level of individual indicators could be subject for future studies.

A limitation was found in the mechanistic, deterministic, and often linear linkages from land use change to social, economic, and environmental impact indicators. The study reported here employed state of the art knowledge and applied it to existing data. However, despite data shortages there is as yet not enough knowledge about nonlinearity, uncertainties, and probabilities regarding the impact of land use changes on social, economic, and environmental processes and their spatio-temporal extents. Nor are there sophisticated indicators that adequately consider uncertainties and nonlinearities of the dynamics of the phenomenon that is to be indicated (Wiggering and

Müller 2004). More disciplinary research is warranted here that can advance the knowledge base upon which interdisciplinary studies such as those for impact assessment can build. Also, modeling activities focusing on interdependencies between land use change and landscape processes have to be intensified (Claessens et al. 2009).

CONCLUSION

The analytical framework for impact assessment reported here provides a chain of analysis that departs from a predominantly economic setting, i. e., drivers, which is translated into a geophysical setting, i.e., land use pressures, and further into an integrated system of the social, economic, and environmental settings, i.e., sustainability impacts. The processed information was meant to feed discussions in the frame of impact assessment processes through multiple scenario comparison.

The adaptation of the DPSIR concept is a technocratic approach to impact assessment that was chosen for reasons of clarity, reproducibility, and potential for integrating all three dimensions of sustainability. However, the framework does not cover the dialogue at the science-policy interface sufficiently to be effectual for the political process of impact assessment. Still, we find the analytical framework to be an adequate basis for an integration of data for decision making purposes. Applied together with communication tools, the framework can very well be applied for an improvement of the dialogue at the science-policy interface. The framework was initially developed for the conditions of the European Union member states. Adaptations of the framework or its parts to other regions of the world were performed for China (Zhen et al. 2009) and Indonesia (König et al. 2010).

The method aimed at integrating top-down data and indicator based modeling with bottom-up, value driven participatory approaches. The translation of the analytical architecture for decision support will help policy makers to comprehend the possible impacts of various scenario-based choice options. The major difference to other approaches lies in the handling of modeling and indicator results. In this framework, modeling and indicator results are aggregated to Land Use Functions, which are the quantitative input into the qualitative valuation process that is furthered by a discursive dialogue with stakeholders. The advantage of complementing the model result with a qualitative approach is a full

recognition of the societal aspects of the definition of sustainable development based on values and trade-off considerations.

Responses to this article can be read online at:
<http://www.ecologyandsociety.org/vol16/iss1/art27/responses/>

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LITERATURE CITED

- Alkan Olsson, J., C. Bockstaller, L. M. Stapleton, F. Ewert, R. Knapen, O. Therond, G. Geniaux, S. Bellon, T. Pinto Correia, N. Turpin, and I. Bezlepina. 2009. A goal oriented indicator framework to support impact assessment of new policies for agri-environmental systems. *Environmental Science & Policy* 12(5):562-572.
- Bach, H., M. Bakker, J. Farrington, Z. Drillet, B. Duray, P. Frederiksen, K. E. Gyuró, T. Henrichs, K. Jansson, T. S. Jensen, S. Jombach, L. Jones, B. Kaae, M. Lindner, A. Lopatka, N. Kohlheb, T. Kuhlman, S. Petit, M. L. Paracchini, L. K. Petersen, L. Reid, D. Rothman, P. Scholefield, N. Schulp, T. Stuczynski, M. van Eupen, P. Verburg, H. Verkerk, J. Vogt, F. P. Vinther, and C. Wilson. 2008. Indicators – methodology and descriptions. SENSOR Deliverable Report 2.3.2. In K. Helming and H. Wiggering, editors. *SENSOR Report Series 2008/7*. ZALF, Müncheberg, Germany. [online] URL: http://www.zalf.de/home_ip-sensor/products/SENSOR_rep_2008_7_Indicators.pdf.

- Bammer, G. 2005. Integration and implementation sciences: building a new specialization. *Ecology and Society* 10(2): 6. [online] URL: www.ecologyandsociety.org/vol10/iss2/art6/.
- Barkman, J., K. Helming, K. Müller, and H. Wiggering. 2004. *Multifunctional landscapes: towards an analytical framework for sustainability assessment of agriculture and forestry in Europe*. Final Report. ZALF, Müncheberg, Germany.
- Beck, S., W. Born, S. Dziock, C. Görg, B. Hansjürgens, K. Henle, K. Jax, W. Köck, C. Neßhöfer, F. Rauschmayer, I. Ring, K. Schmidt-Loske, H. Unnerstall, and H. Wittmer. 2006. *The Millennium Ecosystem Assessment and its relevance for Germany*. UFZ-Report 2/2006. UFZ Centre for Environmental Research, Leipzig, Germany.
- Bills, N., and D. Gross. 2005. Sustaining multifunctional agricultural landscapes: comparing stakeholder perspectives in New York (US) and England (UK). *Land Use Policy* 22:313-321.
- Boardman, J., and J. Poesen, editors. 2006. *Soil erosion in Europe*. John Wiley & Sons, Chichester, UK.
- Böhringer, C., and A. Löschel. 2006. Computable general equilibrium models for sustainability impact assessment. *Ecological Economics* 60 (1):49-64.
- Buanes, A., and S. Jentoft. 2009. Building bridges: institutional perspectives on interdisciplinarity. *Futures* 41:446-454.
- Cairol, D., E. Coudel, and R. Laplana. 2008. Special issue: Multifunctionality of agriculture and rural areas: from trade negotiations to contributing to sustainable development - new challenges for research. *International Journal of Agricultural Resources, Governance and Ecology* 7(4/5):297-436.
- Commission of the European Communities (CEC). 2009. *Impact assessment guidelines*. European Commission, Brussels, Belgium. [online] URL: http://ec.europa.eu/governance/impact/commission_guidelines/commission_guidelines_en.htm.
- Claessens, L., J. M. Schoorl, P. H. Verburg, L. Geraedts, and A. Veldkamp. 2009. Modelling interactions and feedback mechanisms between land use change and landscape processes. *Agriculture, Ecosystems and Environment* 129:157-170.
- Costanza, R., R. d'Arge, R. S. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R. V. O'Neill, J. Paruelo, R. G. Raskin, P. Sutton, and M. van den Belt. 1997. The value of the world's ecosystem services and natural capital. *Nature* 387:253-260.
- Costanza, R., and S. Farber. 2002. Introduction to the special issue on the dynamics and value of ecosystem services: integrating economic and ecological perspectives. *Ecological Economics* 41:367-373.
- de Groot, R. S., A. Wilson, and R. M. J. Boumans. 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics* 41:393-408.
- Demont, M., M. Cerovska, W. Daems, K. Dillen, J. Fogarasi, E. Mathijs, F. Muška, J. Soukup, and E. Tollens. 2008. Ex ante impact assessment under imperfect information: biotechnology in new member states of the EU. *Journal of Agricultural Economics* 59(3):463-486.
- Durand, G., and G. Van Huylenbroeck. 2003. Multifunctionality and rural development: a regional framework. Pages 1-16 in G. Van Huylenbroeck and G. Durand, editors. *Multifunctional agriculture - a new paradigm for European agriculture and rural development*. Ashgate, Aldershot, UK.
- Farrington, J. H., T. Kuhlman, D. S. Rothman, Z. Imrichova, L. Reid, and E. Konkoly-Gyuro. 2008. Reflections on social and economic indicators for land use changes. Pages 325-348 in K. Helming, P. Tabbush, and M. Pérez-Soba, editors. *Sustainability impact assessment of land use changes*. Springer-Verlag, Berlin, Germany.
- Forman, R. T. T., and M. Godron. 1986. *Landscape ecology*. John Wiley & Sons, New York, New York, USA.
- Fougeyrollas, P., P. Le Mouël, and P. Zagamé. 2001. *NEMESIS - New factors demands system: dynamic duality and pooled panel estimation techniques*. NEMESIS Working Paper No 3.2. Paris, France.

Frederiksen, P., and P. Kristensen. 2008. An indicators framework for analysing sustainability impacts of land use change. Pages 293-304 in K. Helming, P. Tabbush, and M. Pérez-Soba, editors. *Sustainability impact assessment of land use changes*. Springer-Verlag, Berlin, Germany.

Gabrielson, P., and P. Bosch. 2003. Environmental indicators: typology and use in reporting. Internal working paper. European Environmental Agency, Copenhagen, Denmark. [online] URL: http://eea.eionet.europa.eu/Public/irc/eionet-circle/core_set/library?l=/management_documentation/indicator_typology/EN_1.0_&a=d.

Gamborg, C., and P. Sandøe. 2006. Controlling biodiversity? Ethical analysis of the case of swine fever and wild boar in Denmark. Pages 119-122 in M. Kaiser and M. E. Lien, editors. *Ethics and the politics of food*. Wageningen Academic Publishers, Wageningen, The Netherlands.

Geist, H. J. 2005. *The causes and progression of desertification*. Ashgate, Burlington, Vermont, USA.

Graveland, C., A. F. Bouwman, B. de Vries, V. Eickhout, and B. J. Strengers. 2002. *Projections of multi-gas emissions and carbon sinks, and marginal abatement cost functions modeling for land use related sources*. RIVM report 461502026. National Institute for Public Health and the Environment (RIVM), Bilthoven, The Netherlands.

Heckelei, T., and W. Britz. 2001. Concept and explorative application of an EU-wide regional agricultural sector model (CAPRI-Projekt). Pages 281-290 in T. Heckelei, H. P. Witzke, and W. Henrichsmeyer, editors. *Agricultural sector modelling and policy information systems*. Proceedings of the 65th EAAE Seminar, March 29-31, 2000 at Bonn University, Vauk Verlag Kiel, Germany.

Helming, K., K. Diehl, T. Kuhlmann, T. Jansson, P. H. Verburg, M. Bakker, M. Pérez-Soba, L. Jones, P. J. Verkerk, P. Tabbush, J. Morris, Z. Drillet, J. Farrington, P. Le Mouél, P. Zagame, T. Stuczynski, G. Siebielec, K. Tscherning, and H. Wiggering. 2011. Ex ante impact assessment of policies affecting land use, Part B: application of the analytical framework. www.ecologyandsociety.org/vol16/iss1/art29/.

Helming, K., P. Tabbush, and M. Pérez-Soba, editors. 2008. *Sustainability impact assessment of land use changes*. Springer-Verlag, Berlin, Germany.

Hertin, J., A. Jordan, M. Nilsson, B. Nykvist, D. Russel, and J. Turnpenny. 2007. *The practice of policy assessment in Europe: an institutional and political analysis*. Working Paper 6. Methods and Tools for Integrated Sustainability Assessment (MATISSE), European Commission, Brussels, Belgium. [online] URL: http://www.matisse-project.net/projectcomm/uploads/tx_article/Working_Paper_6.pdf.

Hoogeveen, Y., and T. Ribeiro. 2007. *Land use scenarios for Europe*. Background Report. European Environmental Agency, Copenhagen, Denmark.

International Panel on Climate Change (IPCC). 2001. *Climate change 2001: the scientific basis*. J. T. Houghton, Y. Ding, D. J. Griggs, M. Noguer, P. J. van der Linden, X. Dai, K. Maskell, and C. A. Johnson, editors. Contributions of Working Group I to the third assessment report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK.

International Panel on Climate Change (IPCC). 2007. *Climate change 2007: impacts, adaptation and vulnerability*. M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, editors. Contributions of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge, UK.

Jacob, K., A. Volkery, A. Lenschow. 2008. Instruments for environmental policy integration in 30 OECD countries. In A. J. Jordan and A. Lenschow, editors. *Innovation in environmental policy? Integrating the environment for sustainability*. Edward Elgar, Cheltenham, UK.

Jansson, T., M. Bakker, B. Boitier, A. Fougereyrollas, J. Helming, H. van Meijl, and P. J. Verkerk. 2008. Cross sector land use modelling framework. Pages 159-180 in K. Helming, P. Tabbush, and M. Pérez-Soba, editors. *Sustainability impact assessment of land use changes*. Springer-Verlag, Berlin, Germany.

- Jones, M. L. M., S. Petit, L. Firbank, N. Bertrand, G. Geffard, M. Rambolinaza, C. Granjou, V. Boudières, L. Omodei-Zorini, C. Contini, B. Hasler, D. de Groot, L. Hein, and J. Luttik. 2006. Risk assessment concepts and regional indicator thresholds. SENSOR Project Deliverable Report 3.2.1. In K. Helming and H. Wiggering, editors. *SENSOR Report Series 2006/05*. ZALF, Müncheberg, Germany. [online] URL: http://www.zalf.de/home_ip-sensor/products/Reporting%20Series/SENSOR_rep_2006_5_RiskAssessment.pdf.
- Kallas, Z., J. A. Gomez-Limon, and M. Arriaza. 2007. Are citizens willing to pay for agricultural multifunctionality? *Agricultural Economics* 26:405-419.
- Karjalainen, T., A. Pussinen, J. Liski, G. J. Nabuurs, T. Eggers, T. Lapveteläinen, and T. Kaipainen. 2003. Scenario analysis of the impacts of forest management and climate change on the European forest sector carbon budget. *Forest Policy and Economics* 5(2):141-155.
- Klijn, J. A., L. A. E. Vullings, R. J. A. Lammeren, J. C. M. van Meijl, T. van Rheenen, A. Veldkamp, P. H. Verburg, H. Westhoek, B. Eickhout, and A. A. Tabeau. 2005. *The EURURALIS study: technical document*. Alterra Report 1196. Alterra, Wageningen, The Netherlands.
- König, H., J. Schuler, U. Suarman, D. McNeill, J. Imbernon, F. Damayanti, S. A. Dalimunthe, S. Uthes, J. Sartohadi, K. Helming, and J. Morris. 2010. Assessing the impact of land use policy on urban-rural sustainability using the FoPIA approach in Yogyakarta, Indonesia. *Sustainability* 2 (7):1991-2009.
- Lotze-Campen, H. 2008. The role of modelling tools in Integrated Sustainability Assessment (ISA). *Innovation and Sustainable Development* 3:70-92.
- Maier, L., and M. Shobayashi. 2001. *Multifunctionality: towards an analytical framework*. Agriculture and Food. Organisation for Economic Co-operation and Development (OECD), Paris, France.
- Metzger, M. J., M. D. A. Rounsevell, L. Acosta-Michlik, R. Leemans, and D. Schröter. 2006. The vulnerability of ecosystem services to land use change. *Agriculture, Ecosystems and Environment* 114:69-85.
- Millennium Ecosystem Assessment (MA). 2003. *Ecosystems and human well-being: a framework for assessment*. Island Press, Washington, D.C., USA.
- Morris, J., M. Camilleri, and S. Moncada. 2008. Key sustainability issues in European sensitive areas – a participatory approach. Pages 451-470 in K. Helming, P. Tabbush, and M. Pérez-Soba, editors. *Sustainability impact assessment of land use changes*. Springer-Verlag, Berlin, Germany.
- Naveh, Z., and A. S. Lieberman. 1994. *Landscape ecology: theory and application*. Second edition. Springer-Verlag, New York, New York, USA.
- Nelson, E., G. Mendoza, J. Regetz, S. Polasky, H. Tallis, D. R. Cameron, K. M. A. Chan, G. C. Daily, J. Goldstein, P. M. Kareiva, E. Lonsdorf, R. Naidoo, T. H. Ricketts, and M. R. Shaw. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment* 7 (1):4-11.
- Niemeijer, D., and R. de Groot. 2006. Framing environmental indicators: moving from causal chains to causal networks. *Environment, Development and Sustainability* 10:89-106.
- Ojima, D. S., K. A. Galvin, B. L. Turner. 1994. The global impact of land use change. *BioScience* 44 (5):300-304.
- Ortiz, R., H. Walton, T. Taylor, S. Arnold, and A. Markandya. 2009. Accounting framework for the assessment of externalities. SENSOR Project Deliverable Report 2.3.4. In Helming, K., H. Wiggering, editors. *SENSOR Report Series 2009/4*. [online] URL: http://www.zalf.de/home_ip-sensor/products/SENSOR_rep_2009_4_Externalities.pdf.
- Paracchini, M. L., C. Pacini, M. L. M. Jones, and M. Pérez-Soba. 2011. An aggregation framework to link indicators associated with multifunctional land use to the stakeholder evaluation of policy options. *Ecological Indicators* 11(1):71-80.
- Pérez-Soba, M., S. Petit, L. Jones, N. Bertrand, V. Briquel, L. Omodei-Zorini, C. Contini, K. Helming, J. Farrington, M. Tinacci Mossello, D. Wascher, F. Kienast, and R. de Groot. 2008. Land use functions –

- a multifunctionality approach to assess the impact of land use change on land use sustainability. Pages 375-404 in K. Helming, P. Tabbush, and M. Pérez-Soba, editors. *Sustainability impact assessment of land use changes*. Springer-Verlag, Berlin, Germany.
- Pimentel, D. 1993. *World soil erosion and conservation*. Cambridge University Press, Cambridge, UK.
- Pierr, A., S. Uthes, Y. Waarts, C. Sattler, K. Happe, and K. Mueller. 2006. Making the multifunctionality concepts operational for impact assessment. Pages 47-54 in B. C. Meyer, editor. *Sustainable land use in intensively used agricultural regions*. Landscape Europe. Alterra Report No. 1338, Wageningen, The Netherlands.
- Plummer, M. L. 2009. Assessing benefit transfer for the valuation of ecosystem services. *Frontiers in Ecology and Environment* 7(1):38-45.
- Poschlod, P., J. P. Bakker, and S. Kahmen. 2005. Changing land use and its impact on biodiversity. *Basic and Applied Ecology* 6(2):93-98.
- Pregernig, M. 2006. Transdisciplinarity viewed from afar: science-policy assessments as forums for the creation of transdisciplinary knowledge. *Science and Public Policy* 33(6):445-455.
- Rametsteiner, E. H. Pulzl, J. Alkan-Olsson, and P. Frederiksen. 2011. Sustainability indicator development—science or political negotiation? *Ecological Indicators* 11(1):61-70.
- Renetzeder, C., M. van Eupen, C. A. Mücher, T. Wrbka. 2008. Clustering Europe: a spatial regional reference framework for sustainability assessment. Pages 249-268 in K. Helming, P. Tabbush, and M. Pérez-Soba, editors. *Sustainability impact assessment of land use changes*. Springer-Verlag, Berlin, Germany.
- Reynolds, J. F., and D. M. Stafford Smith, editors. 2002. *Global desertification: do humans cause deserts?* Dahlem Report 88. Dahlem University Press, Berlin, Germany.
- Rounsevell, M. D. A., I. Reginster, M. B. Araujo, T. R. Carter, N. Dendoncker, F. Ewert, J. I. House, S. Kankaanpää, R. Leemans, M. J. M. Metzger, C. Schmit, P. Smith, and G. Tuck. 2006. A coherent set of future land use change scenarios for Europe. *Agriculture, Ecosystems and Environment* 114:57-68.
- Schöber, B., K. Helming, and H. Wiggering. 2010. Assessing land use change impacts – a comparison of the SENSOR Land Use Function approach with other frameworks. *Journal of Land Use Science* 5 (2):159-178.
- Slee, B. 2007. Social indicators for multifunctional rural land use: the case of forestry in the UK. *Agriculture, Ecosystems and Environment* 120 (1):31-40.
- Svarstad, H., L. K. Petersen, D. Rothman, H. Siepel, and F. Wätzold. 2008. Discursive biases of the environmental research framework DPSIR. *Land Use Policy* 25:116-125.
- Tabbush, P., and P. Frederiksen. 2008. Sustainability impact assessment: need and operation. Pages 35-55 in K. Helming, P. Tabbush, and M. Pérez-Soba, editors. *Sustainability impact assessment of land use changes*. Springer-Verlag, Berlin, Germany.
- The Economics of Ecosystems and Biodiversity (TEEB). 2009. *The Economics of Ecosystems and Biodiversity for national and international policy makers – summary: responding to the value of nature*. The Economics of Ecosystems and Biodiversity (TEEB), Bonn, Germany.
- Thiel, A. 2009. The use of ex-ante modelling tools in European impact assessment: What role does land use play? *Journal of Land Use Policy* 26 (4):1138-1148.
- Thiel, A., and B. König. 2008. An institutional analysis of the use of land use modelling tools for impact assessment in the European Commission. Pages 56-75 in K. Helming, P. Tabbush, and M. Pérez-Soba, editors. *Sustainability impact assessment of land use changes*. Springer-Verlag, Berlin, Germany.
- Troy, A., and M. A. Wilson. 2007. Mapping ecosystem services: practical challenges and opportunities in linking GIS and value transfer. *Ecological Economics* 60(4):852-853.
- Tscherning, K., H. König, B. Schösser, K. Helming, and S. Sieber. 2008. Evolution of ex-ante Impact Assessments (IA) in an international context - a review. Pages 17-34 in K. Helming, P. Tabbush, and M. Pérez-Soba, editors. *Sustainability impact assessment of land use changes*. Springer-Verlag, Berlin, Germany.

Van-Camp, L., B. Bujarrabal, A. R. Gentile, R. J. A. Jones, L. Montanerella, C. Olazabal, and S. K. Sevaradjou. 2004. *Reports of the technical working groups established under the thematic strategy for soil protection*. EUR 21319 EN/1. Office for Official Publication of the European Communities, Luxembourg.

Van Herwijnen, M. 2008. The sustainability A-Test. Chapter 4 in *OECD sustainable development studies conducting sustainability assessments*. Organisation for Economic Co-operation and Development (OECD) Publishing, Paris, France.

Van Huylenbroeck, G., V. Vandermeulen, E. Mettepenningen, and A. Verspecht. 2007. Multifunctionality of agriculture: a review of definitions, evidence and instruments. *Living Reviews of Landscape Research* 1, 3. [online] URL: <http://www.livingreviews.org/lrlr-2007-3>.

Van Ittersum, M. K., F. Ewert, T. Heckeley, J. Wery, J. Alkan Olsson, E. Andersen, I. Bezlepkina, F. Brouwer, M. Donatelli, G. Flichman, L. Olsson, A. E. Rizzoli, T. van der Wal, J. E. Wien, and J. Wolf. 2008. Integrated assessment of agricultural systems – a component-based framework for the European Union (SEAMLESS). *Agricultural Systems* 96:150-165.

Veldkamp, A., and P. H. Verburg. 2004. Modelling land use change and environmental impact. *Journal of Environmental Management*. 72:1-3.

Verburg, P. H., M. Bakker, K. Overmars, and I. Staritsky. 2008. Landscape level simulation of land use change. Pages 211-230 in K. Helming, P. Tabbush, and M. Pérez-Soba, editors. *Sustainability impact assessment of land use changes*. Springer-Verlag, Berlin, Germany.

Verburg, P. H., M. D. A. Rounsevell, and A. Veldkamp. 2006. Scenario-based studies of future land use in Europe. *Agriculture, Ecosystems and Environment* 114:1-6.

Verburg, P. H., W. Soepboer, A. Veldkamp, R. Limpiada, V. Espaldon, and S. A. Sharifah Mastura. 2002. Modeling the spatial dynamics of regional land use: the CLUE-S Model. *Environmental Management* 30(3):391-405.

Weaver, P. M., and A. Jordan. 2008. What roles are there for sustainability assessment in the policy process? *International Journal of Innovation and Sustainable Development* 3(1-2):9-32.

Wiek, A., and C. Binder. 2005. Solution spaces for decision making – a sustainability assessment tool for city-regions. *Environmental Impact Assessment Review* 25:589-608.

Wiggering, H., C. Dalchow, M. Glemnitz, K. Helming, K. Müller, A. Schultz, U. Stachow, and P. Zander. 2006. Indicators for multifunctional land use – linking socio-economic requirements with landscape potentials. *Ecological Indicators* 6:238-249.

Wiggering, H., F. Eulenstein, W. Mirschel, M. Willms, C. Dalchow, and J. Augustin. 2008. The environmental effects of global changes on northeast central Europe in the case of non-modified agricultural management. *Landscape Online* 4:1-17.

Wiggering, H., K. Mueller, A. Werner, and K. Helming. 2003. The concept of multifunctionality in sustainable land development. Pages 3-18 in K. Helming and H. Wiggering, editors. *Sustainable development of multifunctional landscapes*. Springer-Verlag, Berlin, Germany.

Wiggering, H., and F. Müller, editors. 2004. *Umweltziele und Indikatoren. Wissenschaftliche Anforderungen zu ihrer Festlegung und Fallbeispiele*. Springer, Heidelberg, Germany.

World Commission on Environment and Development (WCED). 1987. *Our common future*. Oxford University Press, New York, New York, USA.

Zander, P., A. Knierim, J. C. J. Groot, and W. A. H. Rossing. 2007. Multifunctionality of agriculture: tools and methods for impact assessment and valuation (Editorial). *Agriculture, Ecosystems and Environment* 120:1-4.

Zhen, L., S. Cao, Y. Wei, O. Dilly, X. Liu, F. Li, H. Koenig, K. Tscherning, and K. Helming. 2009. Comparison of sustainability issues in two sensitive areas of China. *Environmental Science and Policy* 12(8):1153-1167.